

COMPARISON OF NDT METHODS TO INSPECT CORK AND CORK FILLED EPOXY BONDS

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ABSTRACT

Sheet cork and cork filled epoxy provide external insulation for the Reusable Solid Rocket Motor (RSRM) on the Nation's Space Transportation System (STS). Interest in the reliability of the external insulation bonds has increased since the Columbia incident. A non-destructive test (NDT) method that will provide the best inspection for these bonds has been under evaluation. Electronic Shearography has been selected as the primary NDT method for inspection of these bond lines in the RSRM production flow. ATK Launch Systems Group has purchased an electronic shearography system that includes a vacuum chamber that is used for evaluation of test parts and custom vacuum windows for inspection of full-scale motors. Although the electronic shearography technology has been selected as the primary method for inspection of the external bonds, other technologies that exist continue to be investigated. The NASA/Marshall Space Flight Center (MSFC) NDT department has inspected several samples for comparison with electronic shearography with various inspections systems in their laboratory. The systems that were evaluated are X-ray backscatter, terahertz imaging, and microwave imaging. The samples tested have some programmed flaws as well as some flaws that occurred naturally during the sample making process. These samples provide sufficient flaw variation for the evaluation of the different inspection systems. This paper will describe and compare the basic functionality, test method and test results including dissection for each inspection technology.



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Comparison of NDT Methods to Inspect Cork and Epoxy Filled Cork Bonds

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Space Transportation System

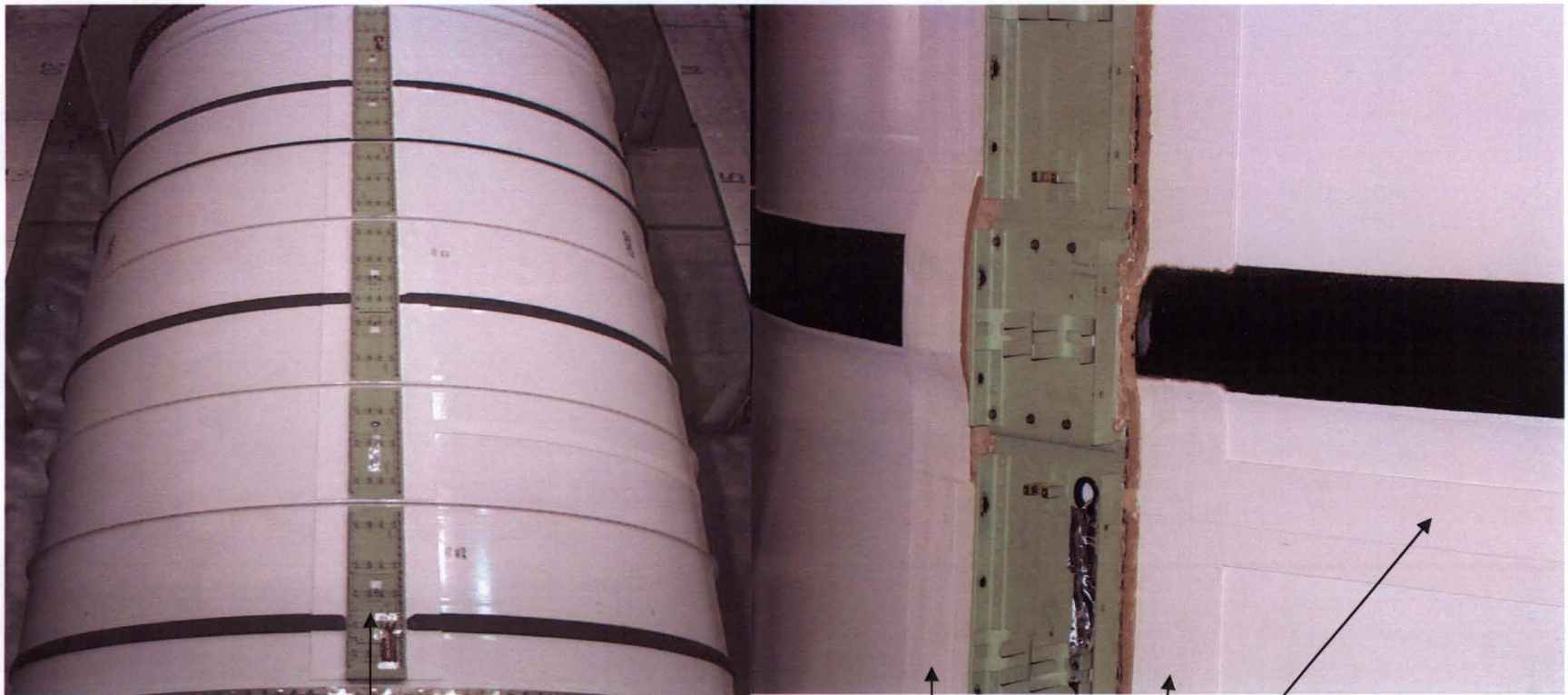


Reusable Solid Rocket Motor (RSRM)

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Reliability of all external bonds has been an interest for the Space Transportation System especially since the Columbia disaster



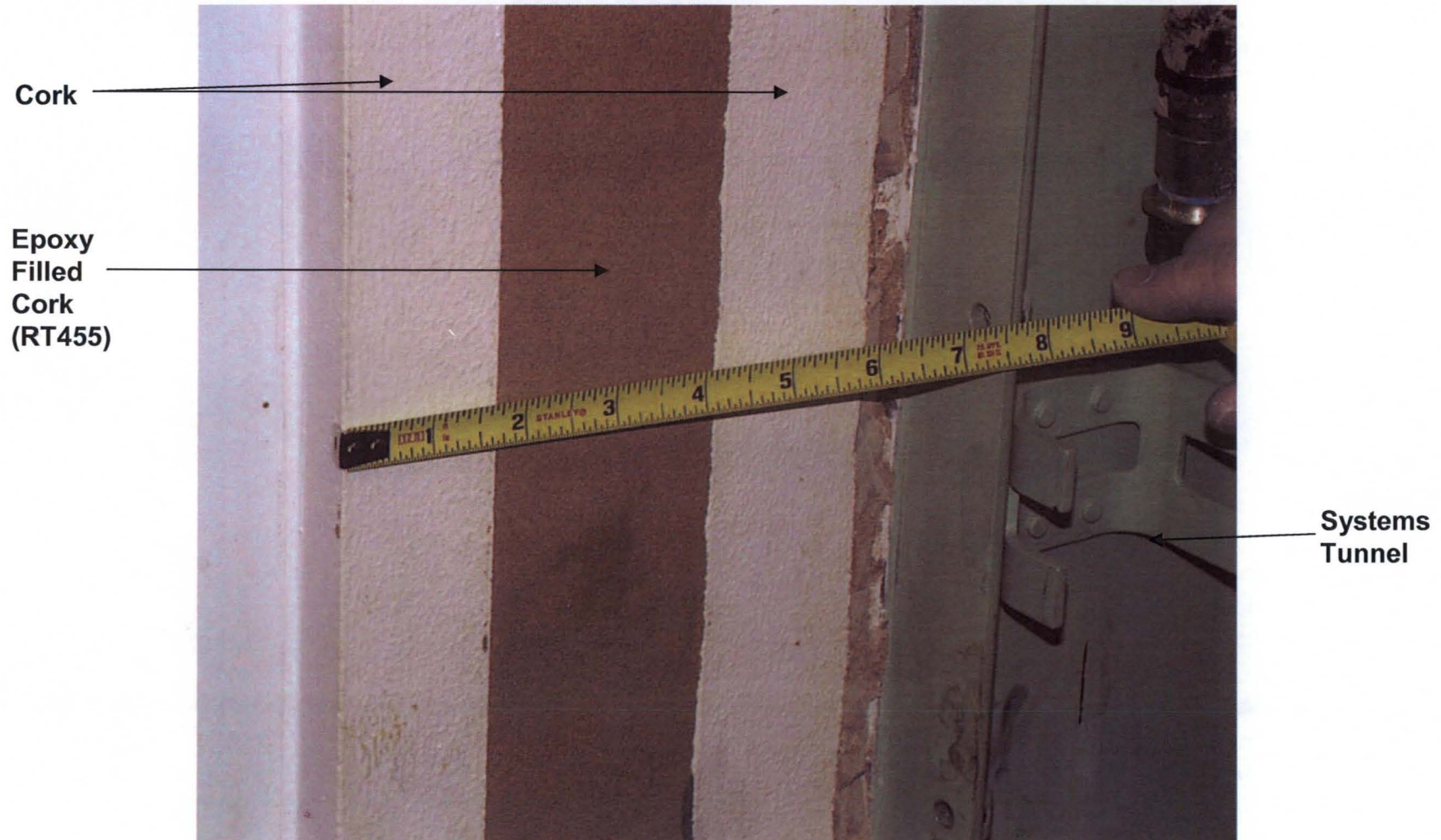
Instrumentation Cables
System Tunnel

Cork and Epoxy Filled Cork
Thermal Protection System (TPS)

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Reliability of all external bonds has been an interest for the Space Transportation System especially since the Columbia disaster



Electronic Shearography has been selected as the NDT method to inspect the RSRM TPS

- Inspection method is capable of detecting voids and un-bonds within existing engineering acceptance criteria
- The technology is mature in field use
- Inspection method is fast
- Method provides permanent record of inspection results

Other technologies exist that are under investigation to inspect the RSRM TPS

- Back Scatter Radiography
- Terahertz imaging
- Microwave imaging

MSFC had systems of each of these technologies and offered to inspect several samples

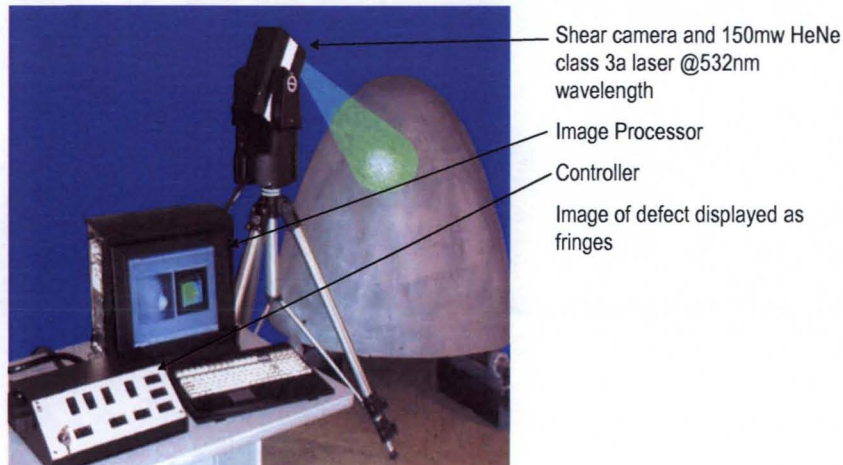
Shearography

Method Description:

- **Shearography detects sub-surface defects and anomalies by observing changes in the surface of the test part resulting from an applied stress**
- The system measures the interference pattern generated by two sheared laser speckle images before and after applied stress
- The result of the interference pattern is a measure of the change in out of plane surface slope which can be directly related to the local stiffness of the structure under test

Advantages:

- Useful in detecting and sizing voids, delaminations, cracks, material inconsistencies in coatings and paints, insulation layers, and polymer or elastomer based structural materials
- The shearographic method images a large area (up to several square feet) of the part under test providing a rapid, near real time, inspection



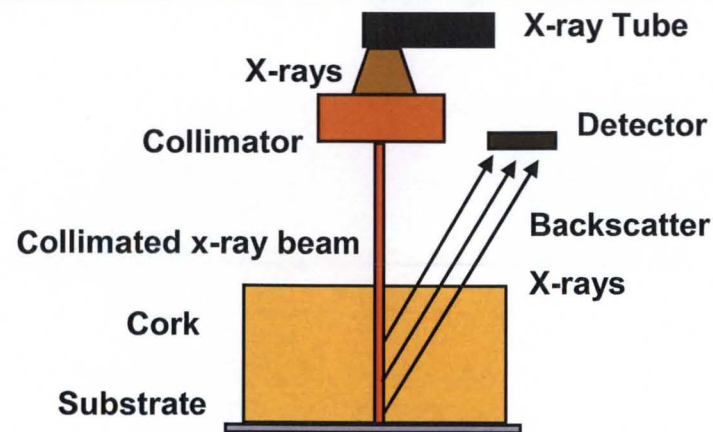
Limitations:

- The part under test must have a surface that will reflect the laser speckle without glare
- The test article must be stable and not move during the acquisition time
- Indications will always be limited to the ability to cause the initial stress on the part

Backscatter Radiography

Method Description:

- A single sided x-ray technique that measures the amount of scattered radiation generated by the interaction of a collimated beam of x-rays on the part under test
- An inspection is performed by rastering the source and detectors by way of a scanning table, producing a 2D image
- The x-rays interact with the material they are passing through and some are scattered back (Compton scattering) toward detectors mounted around the source
- The contrast and resolution are determined by collimator size and scan speed, and can be set to detect defects as small as 1/16"

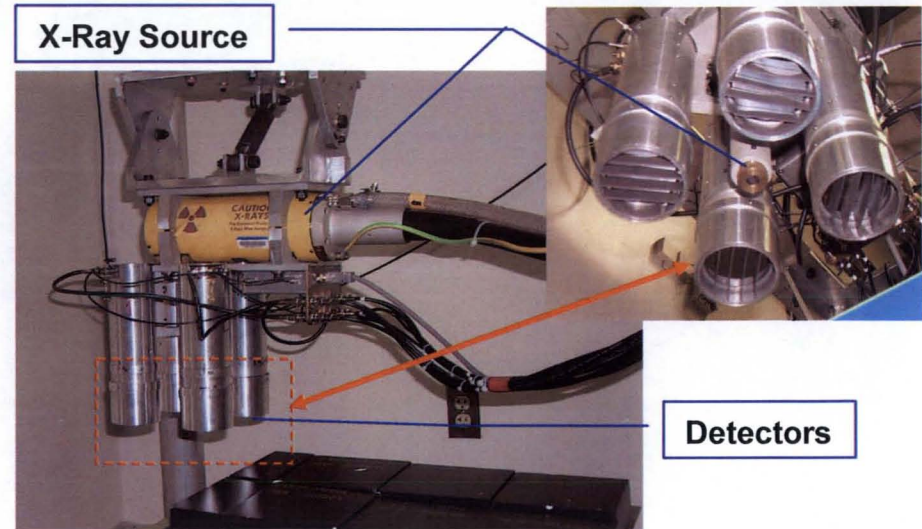


Limitations:

- **Currently very slow, ~1 hour per square foot, although speed is ultimately dependent upon resolution and contrast required**

Advantages:

- **Single sided**
- **Can be performed on wide range of materials including foams, ceramics, composites, metallic and cork**
- **Images produced are similar in readability to that of digital radiography**



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Terahertz Imaging

Method Description:

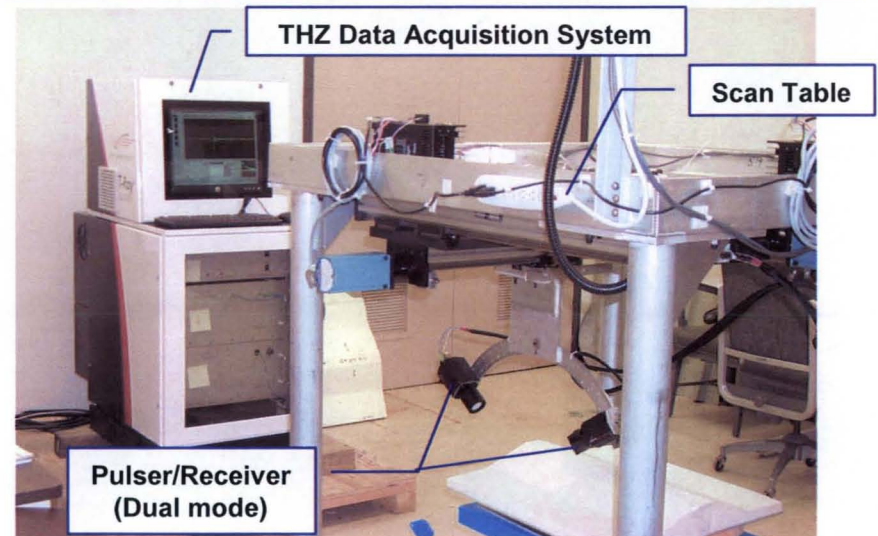
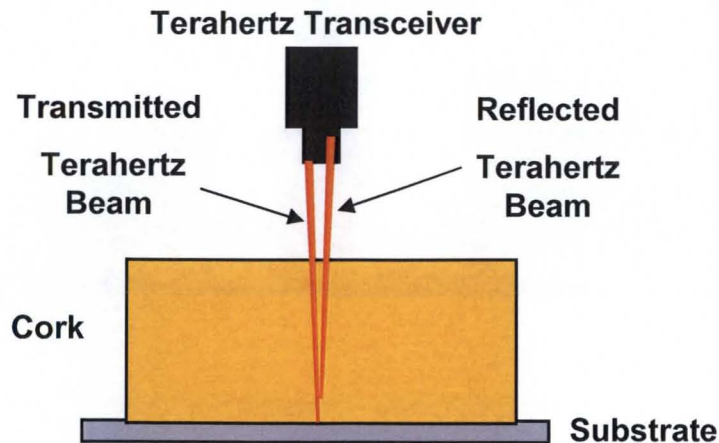
- Analogous to the general operation of ultrasound. Just as with ultrasound a THZ pulse is created at a transmitter, interacts with the material under test and then after either reflecting off a boundary or passing straight through the material is collected at a receiver
- Similar to ultrasound the THZ signals can then be interpreted as individual waveforms for their time domain and frequency content or by scanning to produce an image of the internal volume of the material based on signal features
- Depth of penetration is dictated by the loss factor of the dielectric material and the frequency of operation

Limitations:

- Terahertz signals do not penetrate well inside conductors or graphite composites
- Being a scanner, not an imager, image acquisition is ~ 10 minutes per square foot
- The transmitter and receiver must be aligned at equal angles to the substrate

Advantages:

- Non-contact
- Detection of anomalies in dielectric materials including foams, ceramics, polymers and cork



Radio Frequency (RF) - Microwave

Method Description:

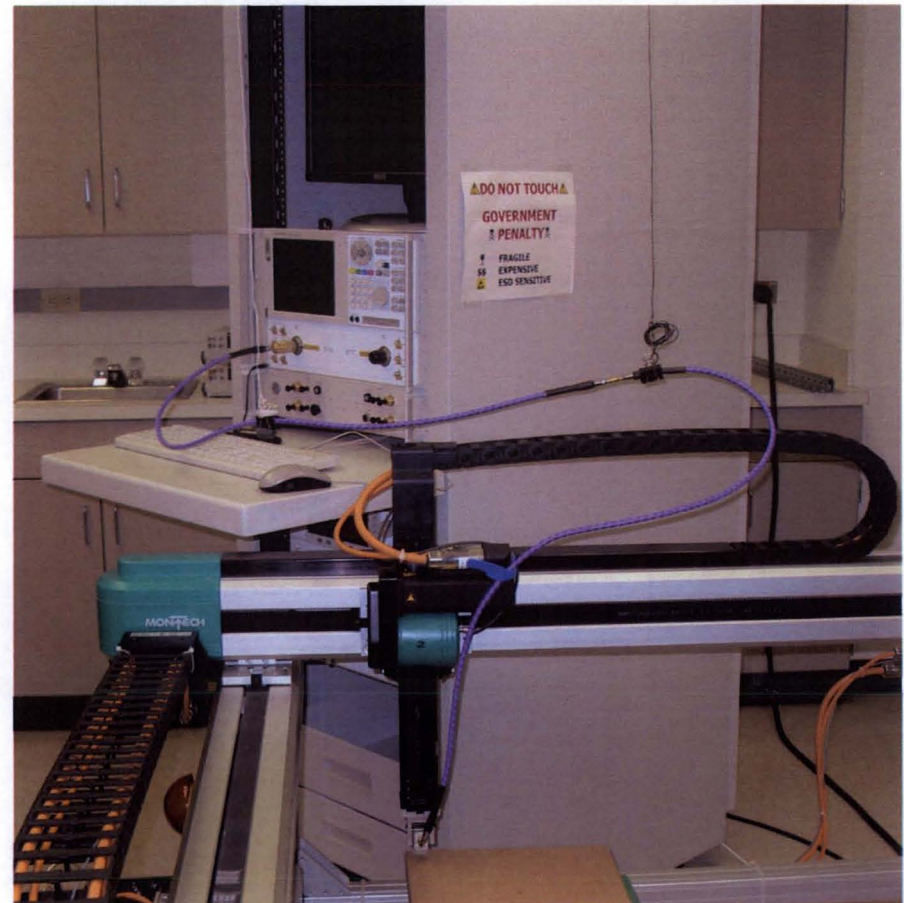
- **The imaging results are like Computed Tomography Slices with the resultant image in 3D**
- Microwave signals penetrate inside dielectric (electrically insulating) media easily
- Depth of penetration is dictated by the loss factor of the dielectric material (ability to absorb microwave energy) and the frequency of operation
- Can be operated on one side or both sides (reflection or transmission techniques)
- Sensitive to geometrical and dimensional variations of medium therefore defects are easily found

Advantages:

- Accurate thickness measurement of coatings, single dielectric slabs, layered dielectric composites
- **Debond, delamination and void detection in dielectric materials**
- Inspection of thick plastics and composites for interior flaws, fiber orientation and breakage and moisture content
- Detection and estimation of porosity in dielectrics
- Impact damage detection and evaluation to include graphite composites
- Accurate material/constituent characterization in dielectric mixtures
- Detection of surface cracks (stress and fatigue) in metals

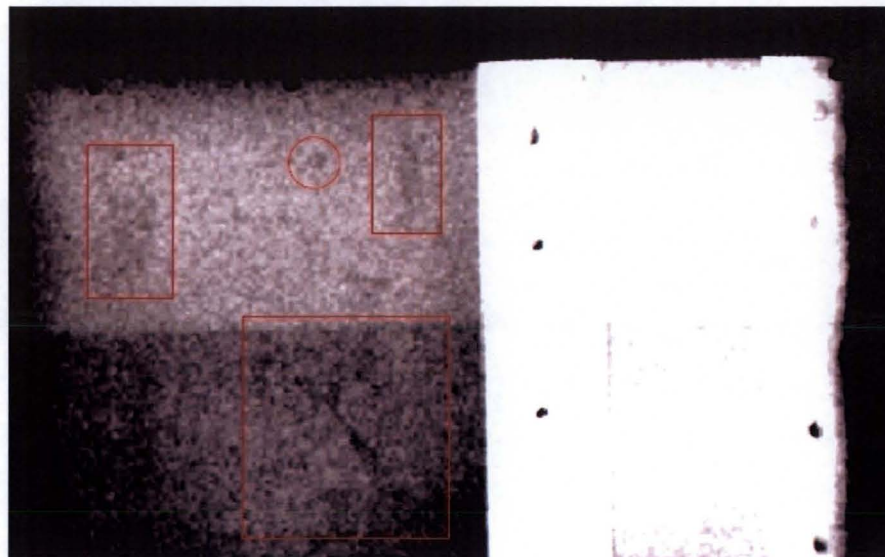
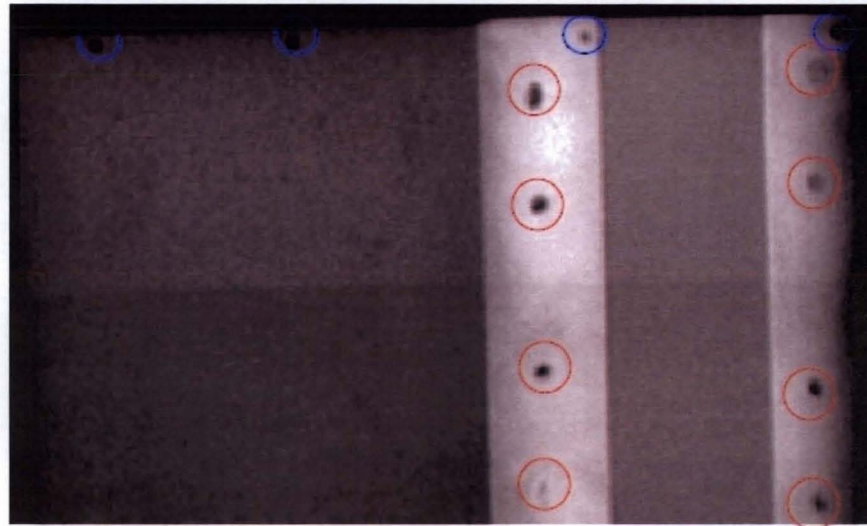
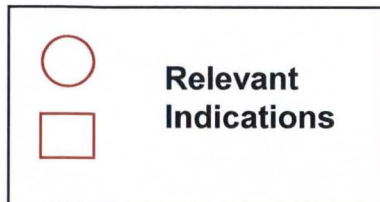
Limitations:

- Microwave signals do not penetrate inside conductors or graphite composites
- Being a scanner, not an imager, image acquisition is slow - ~ 10 to 30 minutes per square foot



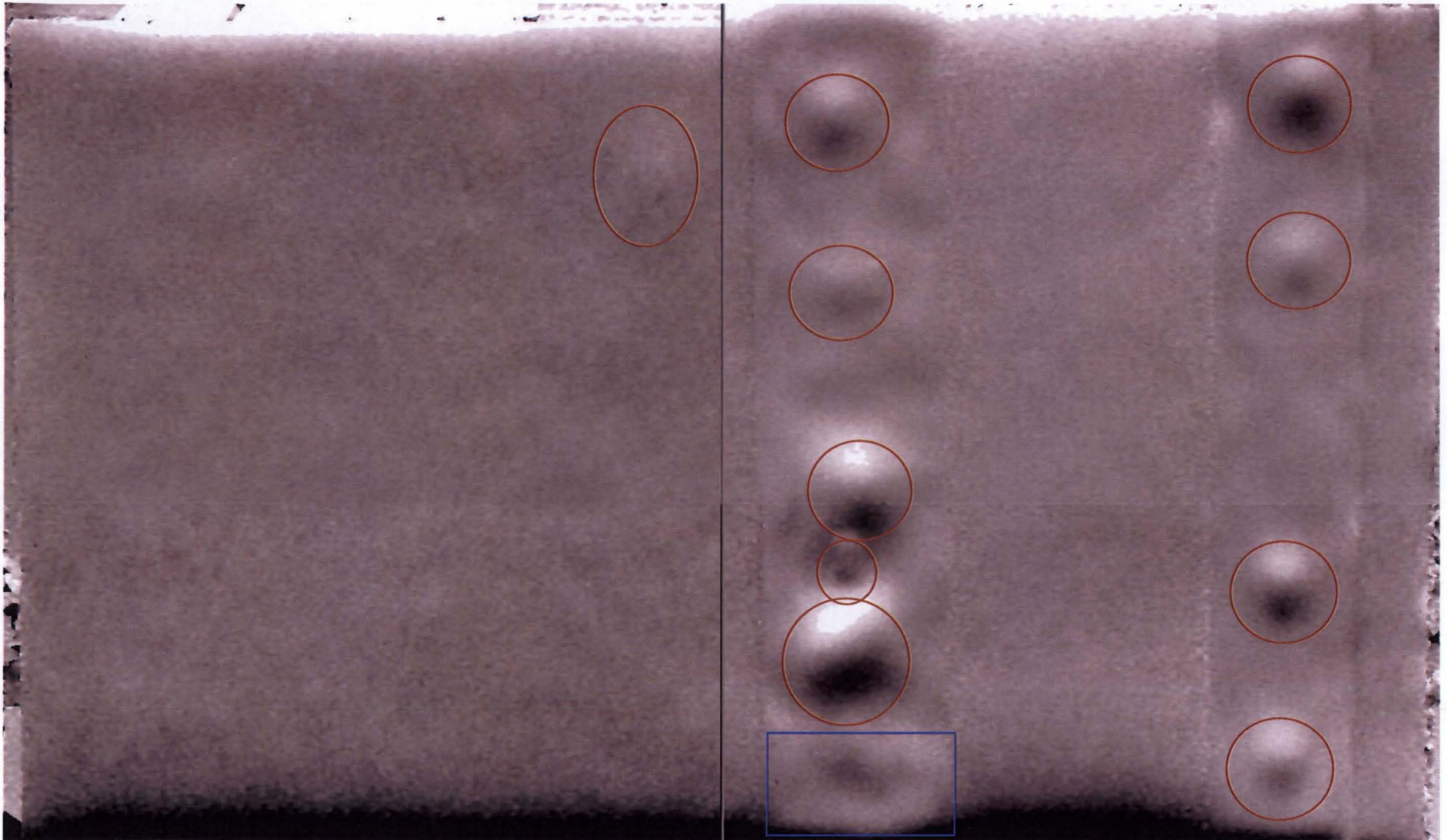
Sample HG4-10

Back Scatter Radiography



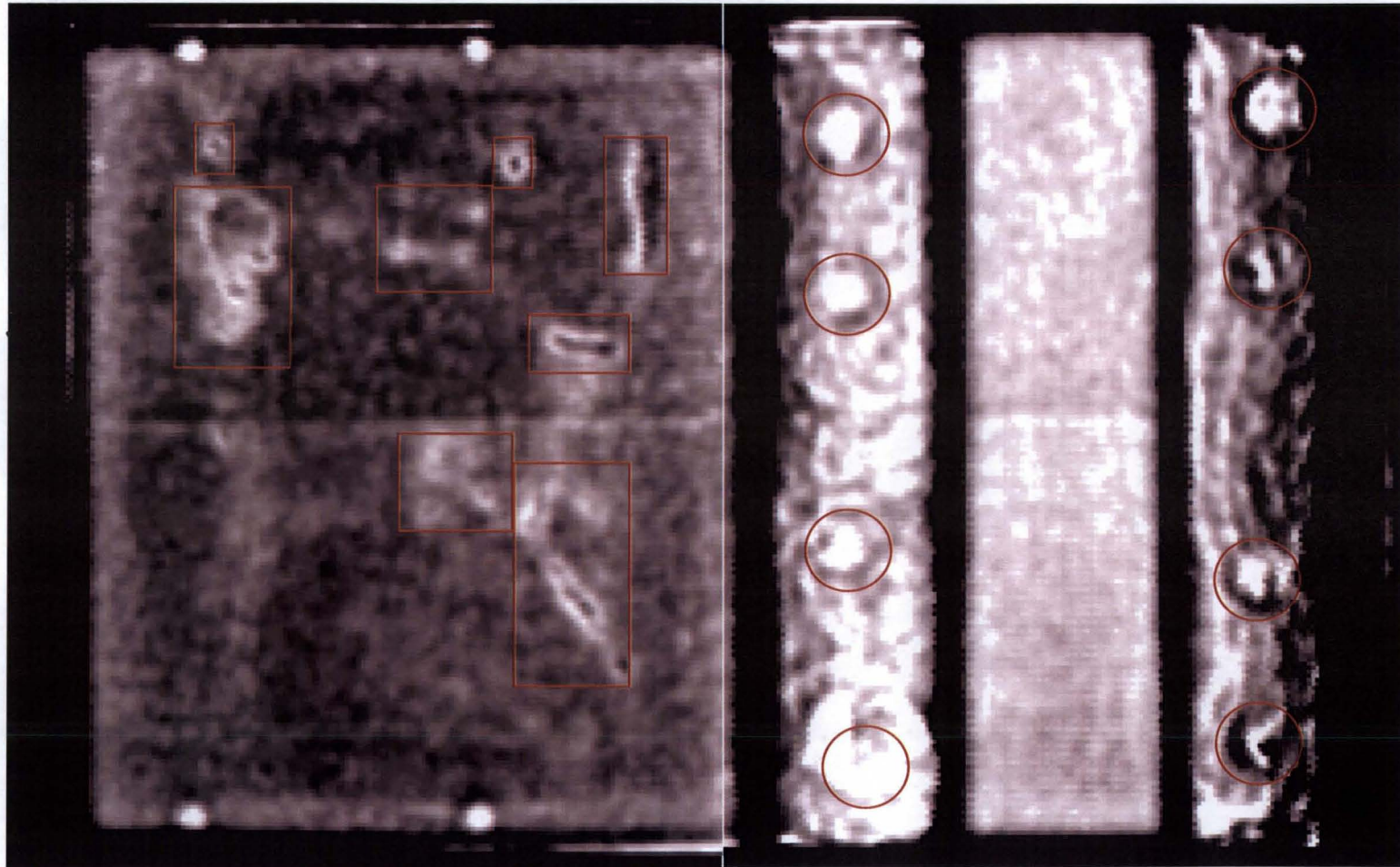
Sample HG4-10

Electronic Shearography



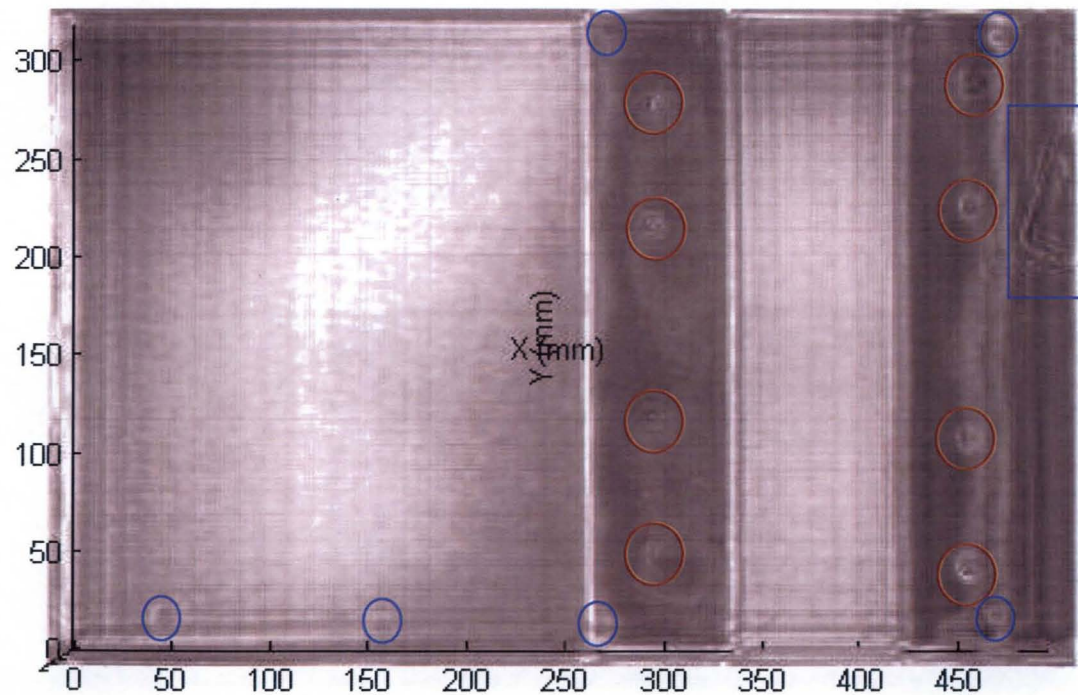
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Terahertz Imaging



Sample HG4-10

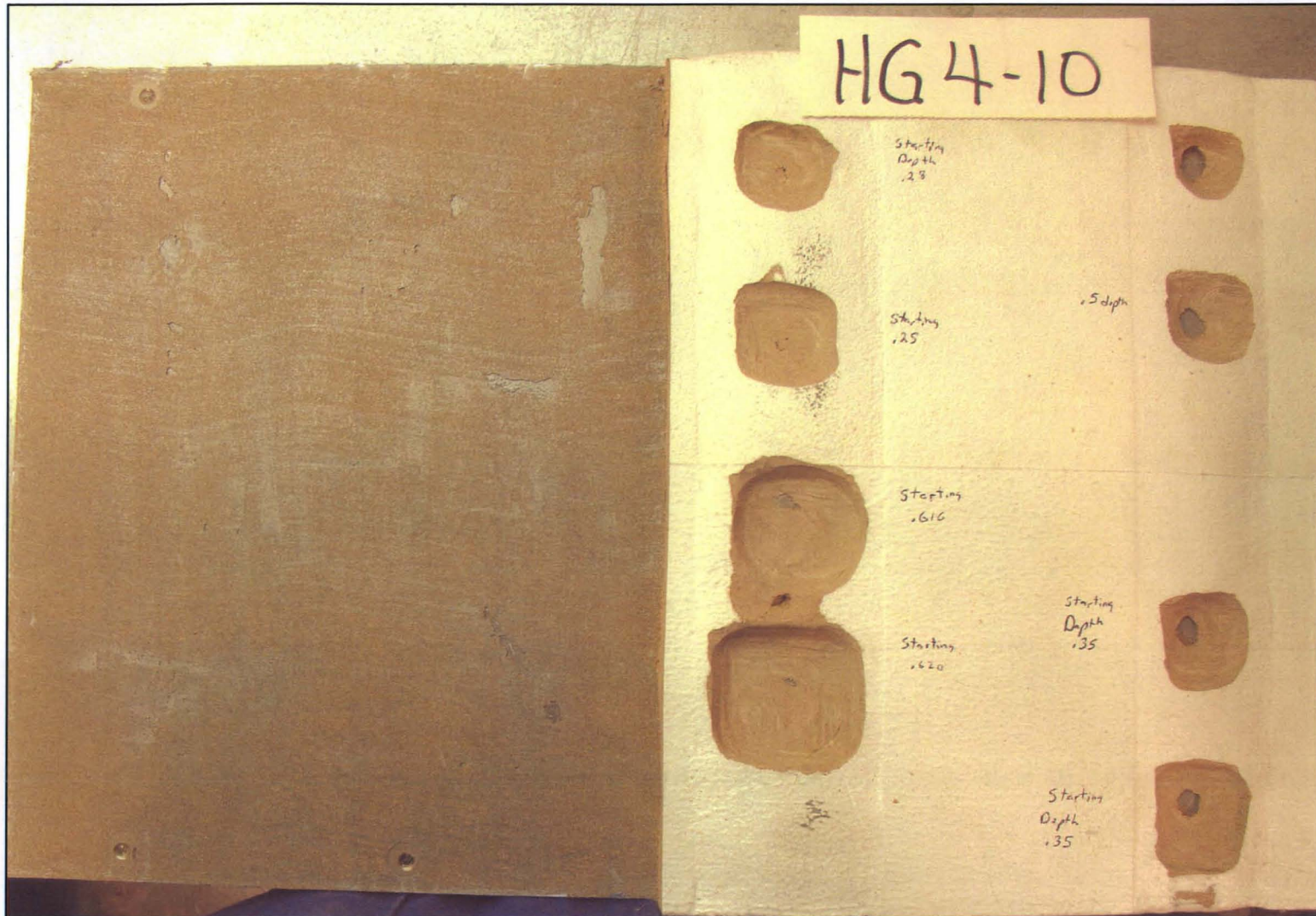
Microwave Imaging



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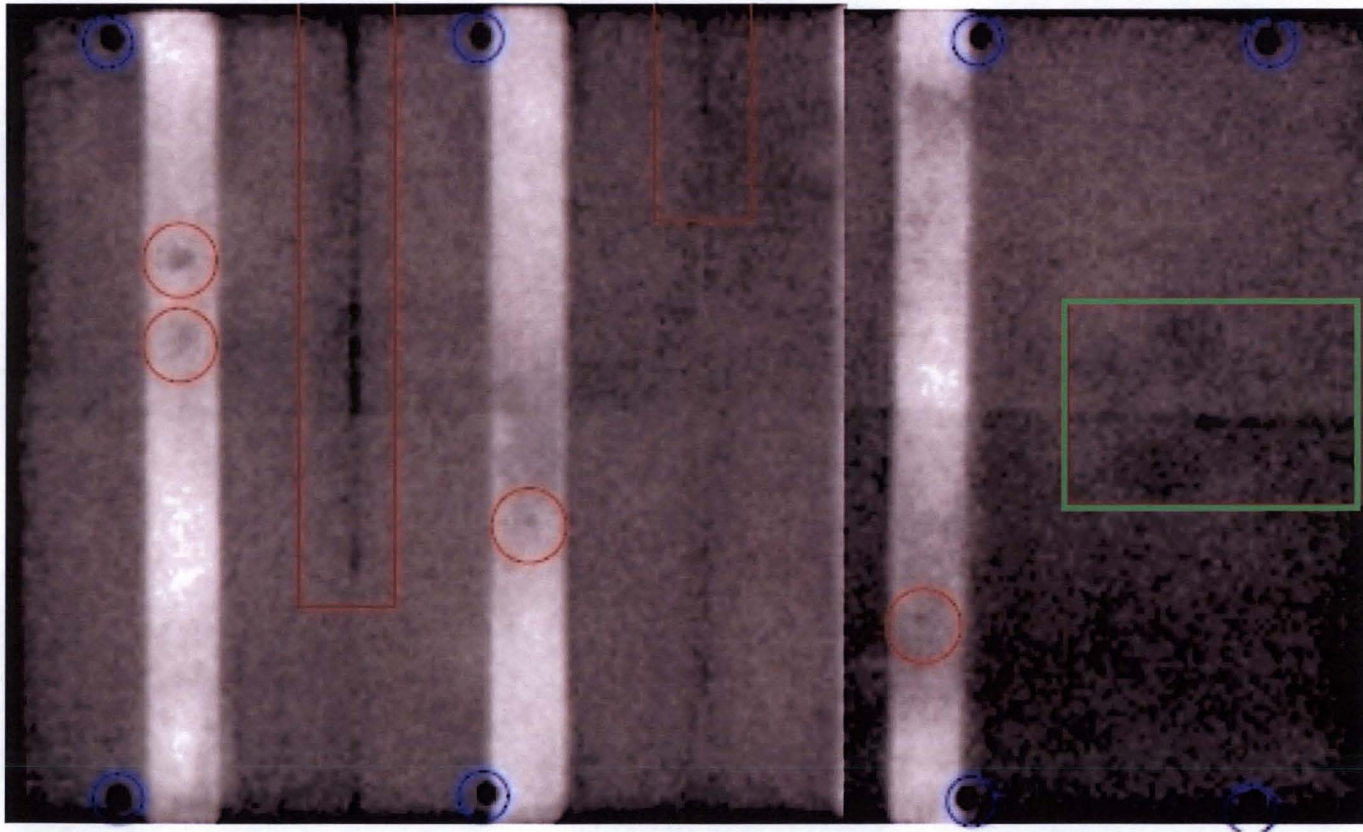
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Sample HG4-10



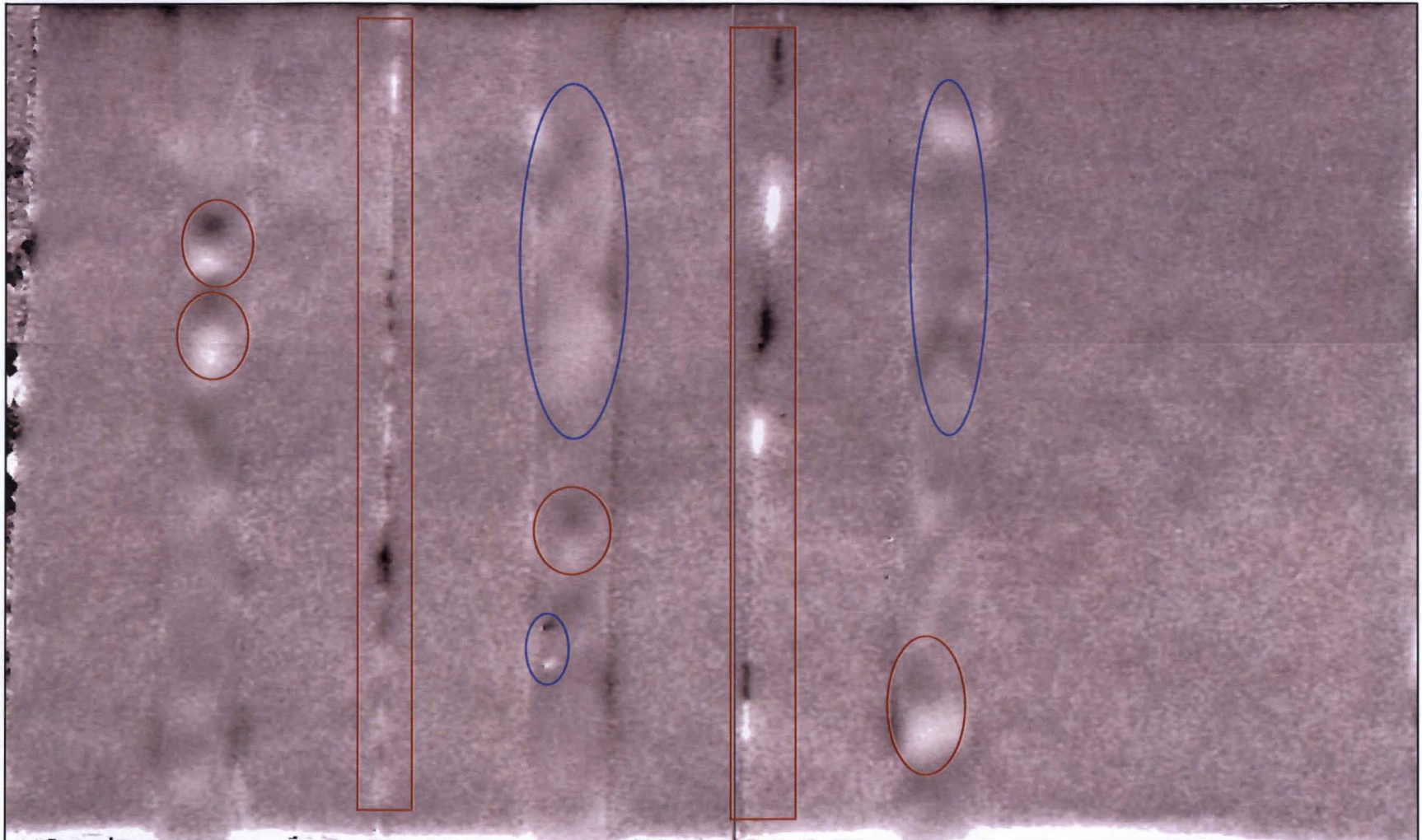
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Back Scatter Radiography



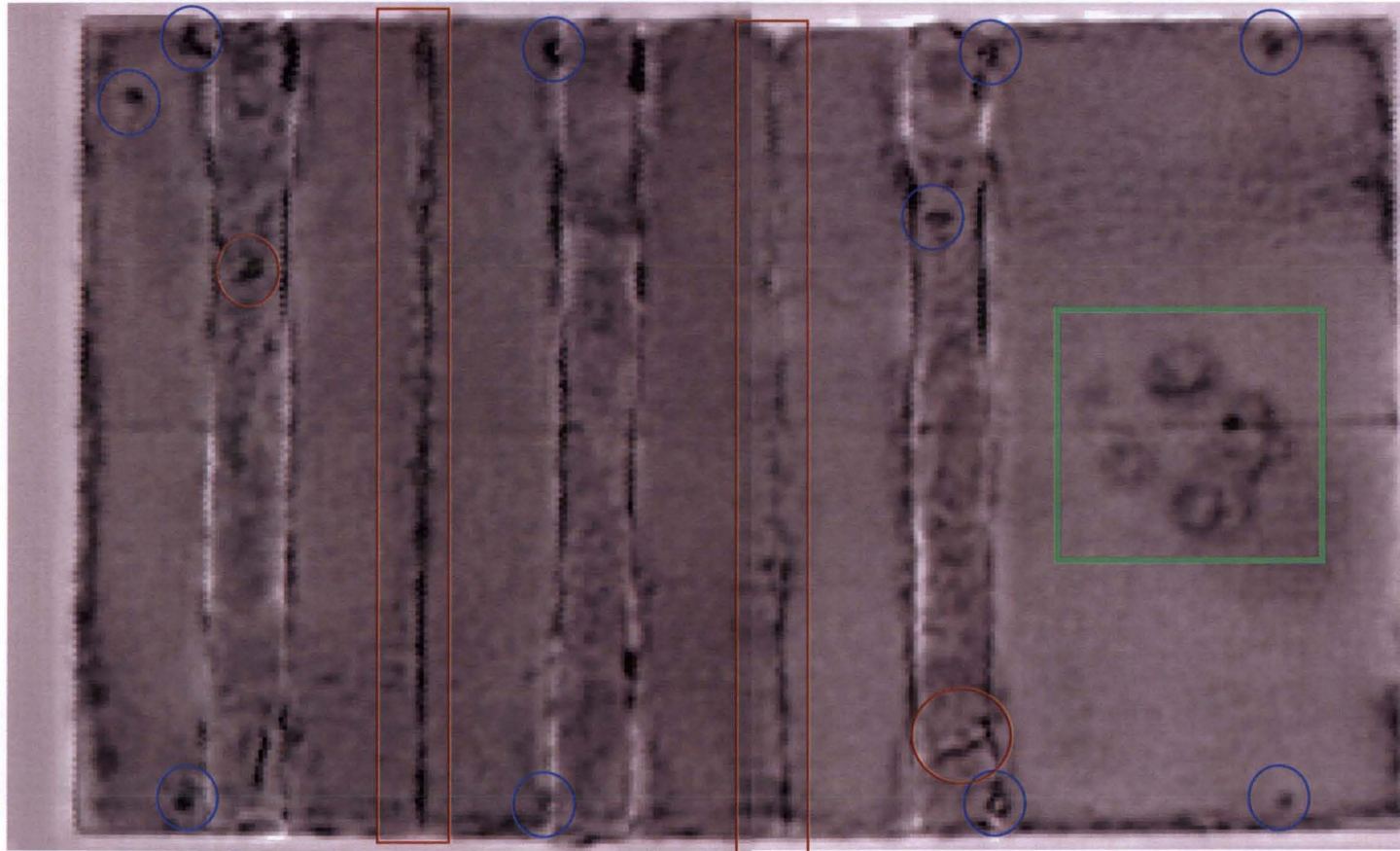
Sample XGEI-9

Electronic Shearography



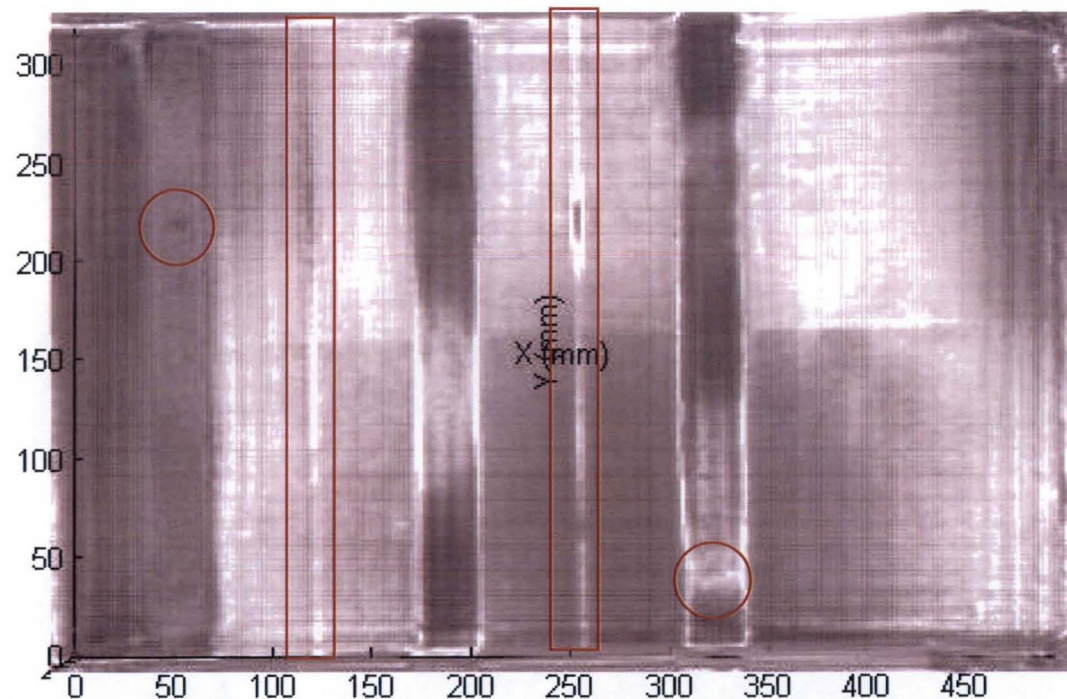
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Terahertz Imaging

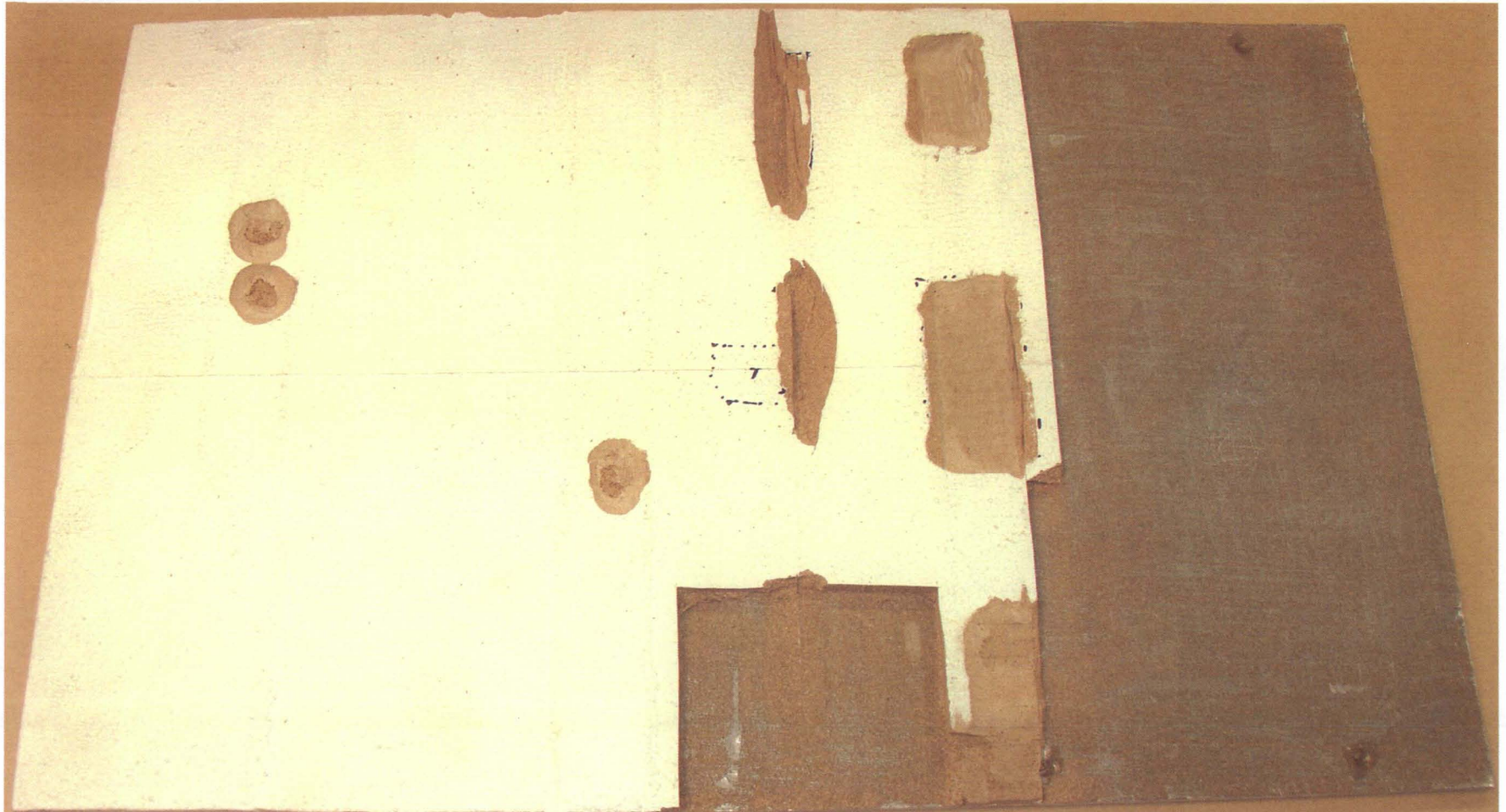


Sample XGEI-9

Microwave Imaging

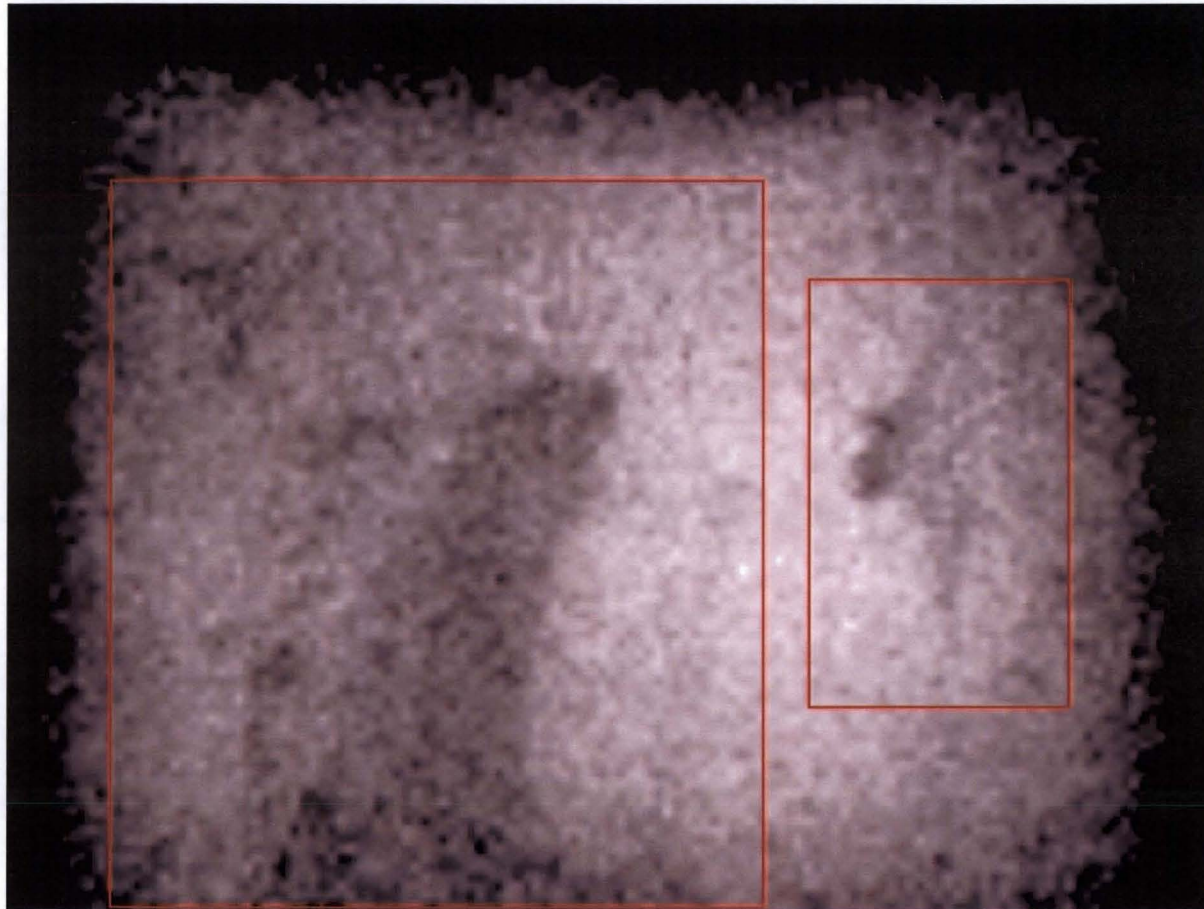


Sample XGEI-9



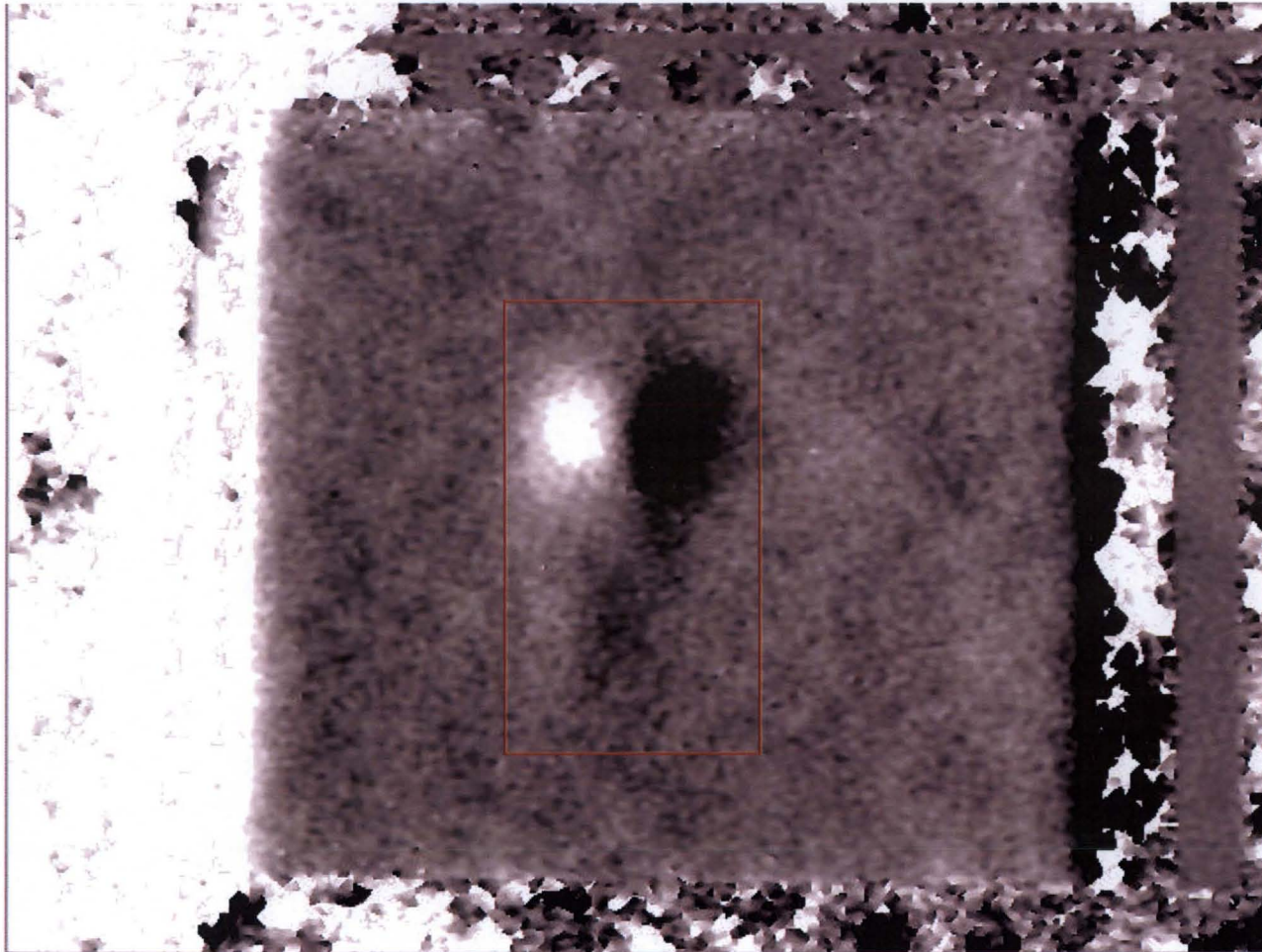
Sample MSL-5

Back Scatter Radiography



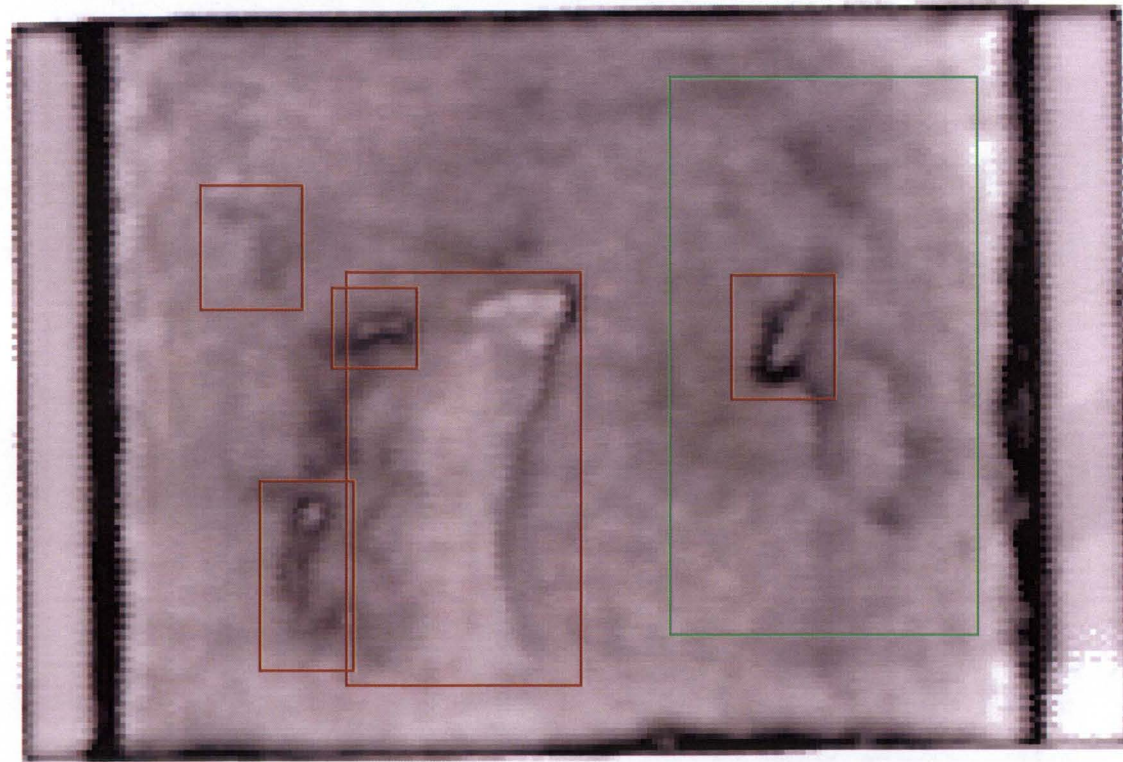
Sample MSL-5

Electronic Shearography



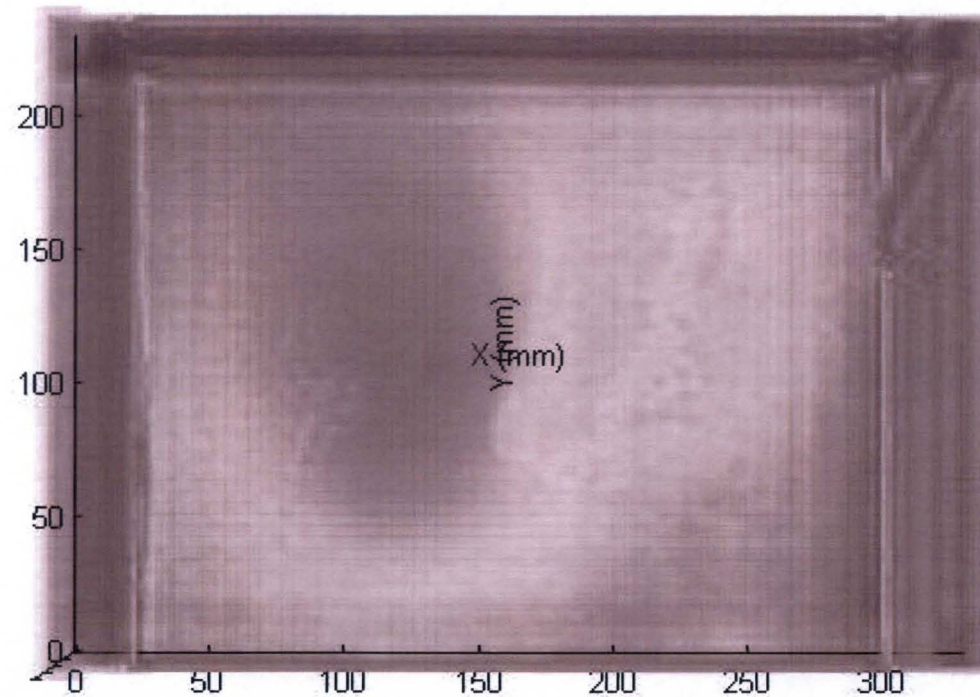
Sample MSL-5

Terahertz Imaging



Sample MSL-5

Microwave Imaging



Sample MSL-5



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	Electronic Shearography	Back Scatter Radiography	Terahertz Imaging	Microwave Imaging
HG4-10 Sheet/RT455	9/9 RT455 voids 1/18 cork to substrate	8/9 RT455 voids 18/18 cork to substrate	8/9 RT455 voids 18/18 cork to substrate	8/9 RT455 voids 0/18 cork to substrate
XGEI-9 Sheet/RT455	4/4 RT455 voids 4/4 cork to cork voids	4/4 RT455 voids 4/4 cork to cork voids 1 false indication	3/4 RT455 voids 4/4 cork to cork voids 1 false indication	2/4 RT455 voids 2/4 cork to cork voids
MSL-5 Sheet	1/26 cork to substrate	26/26 cork to substrate	26/26 cork to substrate	0/26 cork to substrate
HG4-6 Sheet/RT455	3/31 cork to substrate 6/8 RT455 voids	31/31 cork to substrate 7/8 RT455 voids	31/31 cork to substrate 7/8 RT455 voids	0/31 cork to substrate 7/8 RT455 voids
XFJPS-2 Sheet/RT455	8/8 RT455 voids	8/8 RT455 voids	8/8 RT455 voids	8/8 RT455 voids
MSL-4 RT455	4/4 voids	4/4 voids	2/4 voids	2/4 voids

Summary of test result table

- **Electronic Shearography**

- Less sensitive than the other methods, did not detect many of the small defects
- Able to detect all defects greater than critical flaw size in both the cork and the RT455 materials
- Sensitive to poor mixtures of the RT455 material

- **Back Scatter Radiography**

- Capable of detecting very small defects in both the cork and the RT455 materials
- Missed only 2 flaws, both near the surface and in the RT455 material
- False indication data needs to be understood
- Indications of a group of very tiny defects give the appearance of 1 large defect

- **Terahertz Imaging**

- Capable of detecting very small defects in both the cork and the RT455 materials
- Missed only 4 flaws, all near the surface and in the RT455 material
- False indication data needs to be understood
- Indications of a group of very tiny defects give the appearance of 1 large defect

- **Microwave Imaging**

- Capable of detecting very small defects in the RT455 material
- Unable to penetrate the cork to substrate bond line

In Conclusion

- All technologies tested have some promise as a viable method to inspect the TPS materials used on RSRM hardware
 - Further development work would be needed for any of the methods
 - Due to their inability to penetrate conductors, terahertz and microwave imaging remain a concern for their ability to detect substrate to sheet cork un-bonds
 - The adhesive used to bond the sheet cork is a metal filled adhesive
 - Adhesive is applied to both the sheet cork and the substrate
 - Over sensitivity would remain a concern with Back Scatter Radiography and Terahertz Imaging
- Electronic Shearography is not as sensitive as the other methods tested
 - But is still the best choice for this application
 - The method can detect the critical flaw size
 - The method can be implemented into the work place
 - Fast
 - Mature

Questions?